

Survey Manual

Chapter 3

GPS/GNSS Surveys

Colorado Department of Transportation
2021

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3.14.1

3.1 Acronyms found in this chapter

CBN	Cooperative Base Networks
CDOT	Colorado Department of Transportation
CORS	Continuously Operating Reference Stations
CRS	Colorado Revised Statutes
DOP	Dilution Of Precision
DTD	Division of Transportation Development
ECEF	Earth Centered Earth Fixed
EDMI	Electronic Distances Measuring Instruments
FBN	Federal Base Networks
FCC	Federal Communications Commission
FGCS	Federal Geodetic Control Subcommittee
FGDC	Federal Geographic Data Committee
FHWA	Federal Highway Administration
GIS	Geographic Information system
GNSS	Global Navigation Satellite Systems
GPS	Global Positioning System
HARN	High Accuracy Reference Network
HDOP	Horizontal Dilution Of Precision
ITRF	International Terrestrial Reference Frame
ITRF00	International Terrestrial Reference Frame of 2000
LSCD	Land Survey Control Diagram
NAD83	North American Datum of 1983
NAVD88	North American Vertical Datum of 1988
NGS	National Geodetic Survey
NOAA	National Oceanic and Atmospheric Administration
NOS	National Ocean Survey
NSRS	National Spatial Reference System
PCD	Project Control Diagram
PDOP	Positional Dilution of Precision
PLSS	Public Land Survey System
PPK	Post-Processed Kinematic
PPM	Parts Per Million
RINEX	Receiver Independent Exchange Format
RTK	Real-Time Kinematic
RTN	Real Time Network
RTVRN	Real Time Virtual Reference Network

TMOSS	Terrain Modeling Survey System
UDN	User Densification Networks
VDOP	Vertical Dilution Of Precision
VRN	Virtual Reference Network

Statement of Professional Judgement

The CDOT Survey Manual is intended to be used as a guide for Surveyors working on all projects administered by CDOT, to ensure minimum accuracies and data quality standards are met. It is not the intent of this Manual to supersede the use of Professional judgement or conduct.

3.1.1 If the Professional Land Surveyor in responsible charge of work performed for a CDOT project would like to propose methods which deviate from procedures as outlined in this manual without sacrificing accuracy or quality, those deviations will ONLY be accepted with prior documented approval from the CDOT Regional Professional Land Survey Coordinator who has direct oversight responsibility for the project.

Purpose of this Chapter

3.1.2 The purpose of this chapter is to define the specifications that shall be followed while performing GPS/GNSS surveys for CDOT by CDOT surveyors or contract consultant surveyors. As advances in GPS technology are made in hardware and processing software that prove a higher degree of accuracy is more easily attained, new specifications for CDOT may be required and sections of this chapter revised to stay current with those advances.

For brevity, GPS/GNSS shall be referred to as GPS throughout the Survey Manual.

Any variation from the specifications shall have the prior approval of the Region Survey Coordinator.

3.1.3 GPS Methods

A wide variety of GPS survey methods are accepted by CDOT. These methods vary in the type of equipment used, length of observation times, and the accuracy that is attained. GPS survey methods that are most commonly used within CDOT include but are not limited to the following:

1. Static
2. Fast Static
- 3.1.4 3. Real Time Kinematic (RTK)
4. Post Processed Kinematic (PPK)

Specifications

3.1.5 The specifications included in this chapter are based on the Geospatial Positioning Accuracy Standards as published by the Federal Geodetic Control Subcommittee (FGCS) of the Federal Geographic Data Committee (FGDC).

These standards and specifications have been modified to best suit the needs of CDOT.

Specification Types

There are two types of specifications that shall be followed while performing GPS surveys for CDOT as follows:

1. FGDC/FGCS Standards and Specifications - for surveys that are submitted for inspection and acceptance into the National Spatial Reference System (NSRS) database by federal approval (See 23 CFR 630.402 – Geodetic, for additional information.)
2. CDOT Specifications - for surveys that are not to be submitted for inspection and acceptance into the national database by federal approval.

National Geodetic Survey (NGS) Index of FGDC Accuracy Standards:

http://www.fgdc.gov/standards/standards_publications/index.html

The above link provides downloads of the following FGDC Accuracy Standards.

Continually Operating Reference Stations (CORS) and NSRS

3.1.6

- The CORS will be the primary way for accessing the NSRS in the future through GNSS based surveys. There will be procedures to use GNSS and constraints even for geodetic leveling surveys opposed to using heights on benchmarks to access NAVD88 like today.
- Passive control will still be an important component of the NSRS, but it will no longer be what is used to define the NSRS.
- The modernized NSRS will have data submitted that will become “part of” the NSRS as well as data submitted that will be “tied to” the NSRS. The differences between these two types of data will be that the data that becomes “part of” the NSRS will be data that is processed and adjusted by NGS to determine Reference Epoch Coordinates and Survey Epoch Coordinates.
- See <https://www.ngs.noaa.gov/> for more information regarding newer NGS tools and terminology.

GPS surveys for new CDOT projects shall be referenced and tied into the latest adjustment of NAD83 as defined by the NGS for the NSRS. NGS plans to release a new North America reference frame in 2022-2024. All CDOT projects should specify the NGS datums and adjustments used and when the New NGS datums are used after they are released. Existing projects may be tied to an older system with concurrence from the Region Survey Coordinator. Order of surveys are defined by the FGDC Geospatial Positioning Accuracy Standards, Part 2: Standards for Geodetic Networks by the FGCS.

The <https://geodesy.noaa.gov/NGSDataExplorer/> provides geodetic control throughout the United States. Although known by other agency names in the past, the NGS is the primary source for geodetic data in Colorado. Current CDOT projects use NAD83 (2011) to tie to the NSRS.

NOAA’s NGS defines, maintains, and provides access to the NSRS; a consistent coordinate system that defines latitude, longitude, height, scale, gravity, orientation, and shoreline throughout the United States. More recently, NGS has fostered a network of CORS where each CORS includes a highly accurate receiver that continuously collects radio signals broadcast by

Global Navigation Satellite System (GNSS) satellites. NSRS provides the foundation for transportation, communication, and defense systems, boundary and property surveys, land records systems, mapping and charting, and a multitude of scientific and engineering applications. NGS also conducts research to improve the collection, distribution, and use of spatial data.

Surveyors, GIS users, engineers, scientists, and other people who collect GPS/GNSS data can use NCN data, acquired at fiducial geodetic control stations, to improve the precision of their positions, and align their work within the NSRS. NCN enhanced post-processed coordinate accuracies can approach a few centimeters, both horizontally and vertically.

The CORS network is a multi-purpose, multi-agency cooperative endeavor, combining the efforts of hundreds of government, academic, and private organizations. The stations are independently owned and operated. Each agency shares their GNSS/GPS carrier phase and code range measurements and station metadata with NGS, which are analyzed and distributed free of charge.

NGS/NOAA Datasheets:

<https://www.ngs.noaa.gov/datasheets/>

The above link provides for searching and downloading of datasheets for HARN stations.

In areas where the HARN has not yet been established or is lost, a HARN Densification survey (HARND) shall be performed under the FGDC/FGCS standards as outlined by the Region Survey Coordinator and NOAA/NGS. (See Section 3.4, page 20 of this Chapter; [HARN Densification Surveys \(HARND\)](#), for additional information.)

3.1.7 Any other type of survey performed for CDOT that will be submitted for acceptance into the NSRS national database by inspection and approval of the federal government shall be performed under the correct and current federal governments agencies standards and specifications.

GPS Reports

All reports generated from any GPS survey shall be submitted to the Region Survey Coordinator for review and shall be filed in the region survey office records for the project. Reports shall bear the signature and seal of the professional land surveyor in responsible charge and contain a statement that the report was prepared under his/her direct supervision and checking.

Static and Fast Static survey reports shall include the following:

1. Project report
2. Names of individuals and their duties
3. Project sketch or map showing project location and project network
4. Station descriptions
5. Station photographs
6. Station obstruction diagrams

7. Observation logs
8. Equipment logs stating manufacturer, model, serial numbers, and equipment settings
9. Raw observations
10. Baseline processing results
11. Loop closures
12. Repeat baseline analysis
13. Least squares minimum constrained adjustment results
14. Least squares fully constrained adjustment results
15. Elevation report of GPS derived elevations compared with differential leveled elevations
16. Geodetic Coordinate Report including but not limited to the following for each point:
 - a. Point name
 - b. Latitude and longitude
 - c. State plane coordinates based on the geographically reprojected project datum.
 - d. Ellipsoid height
 - e. Differential leveled elevation based on the project datum.
 - f. Mapping angle (convergence)
 - g. Combined Scale factor
 - h. Point description
 - i. Statement of processing software and version, geoid model, ellipsoid, project sea level factors, project scale factors, project combined factors, metric to English conversion factors, project truncation coordinate reduction factors
17. Geographically re-projected Project Coordinate Report including but not limited to the following for each point:
 - a. Point name
 - b. Modified state plane northing
 - c. Modified state plane easting
 - d. Differential leveled North American Vertical Datum of 1988 (NAVD88) elevation
 - e. Point description
 - f. Terrain Modeling Survey System (TMOSS) format tabulation of monuments file in both feet and meters including a GPS file.
 - g. For CDOT Class A – Primary surveys, a primary control coordinate comparison report of the final adjusted control coordinates and ground distances between 68% of all directly connected intervisible adjacent control monuments should be verified to be within the Minimum Horizontal Accuracy Tolerance for a CDOT Class A – Primary survey by conventional survey methods such as a total station with an electronic distance meter. (See Section 3.8, this Chapter for CDOT Class A – Primary Horizontal Surveys, for additional information.)

RTK and PPK survey reports shall include the following:

1. Project report

2. Names of individuals and their duties
3. Project sketch or map showing project location
4. Equipment logs stating manufacturer, model, serial numbers, and equipment settings
5. Calibration report for all points used in the calibration, rotation, scale factor, horizontal and vertical residuals, geoid model (See [RTK Site Calibrations](#), for additional information.)
6. Primary control checks immediately after each initialization, during roving while initialized, and before ending the session
7. Post processed report for any points located with PPK and include control checks completed after adjustments. The method used for verifying the control is also required.
8. Project Coordinate Report including but not limited to the following for each point: Region coordinators may also request the raw data files in pdf format.
 - a. Point name
 - b. Modified state plane northing
 - c. Modified state plane easting
 - d. NAVD88 elevation (See [GPS Derived Orthometric Heights \(Elevations\)](#), for additional information.)
 - e. Point TMOSS code
9. For CDOT Class B – Secondary surveys final RTK or PPK project coordinates for 100% of the following survey monuments shall be verified to be within the Minimum Horizontal Accuracy Tolerance for a CDOT Class B – Secondary survey by observing each survey monument with a minimum of two independent RTK or PPK observation sessions (i.e. two separate initializations) with substantially different GPS constellations (i.e. more than two hours apart and substantially different times of the day). The base receiver should reference a different primary project control monument for the second session. If dual bases are used to reference two primary control monuments 100% of the following survey monuments shall be observed by a minimum of one RTK or PPK observation session from each base reference station (See [CDOT Class B – Secondary Horizontal Surveys](#), for additional information.):
 - i. Secondary Control monuments
 - ii. Public Land Survey System monuments
 - iii. Right-of-Way monuments

* Unless approved otherwise by the Region Survey Coordinator all GPS Photo Control monuments shall be observed only by Static or Fast Static survey methods and procedures in accordance with CDOT Survey Manual Chapter 4 – Aerial Surveys.

10. For CDOT Class B – Secondary surveys final RTK or PPK project coordinates for a minimum of 68%* of the following survey monuments shall be verified to be within the Minimum Horizontal Accuracy Tolerance for a CDOT Class B – Secondary survey by observing each survey monument with a minimum of two independent RTK or PPK observation sessions (i.e. two separate initializations) with substantially different GPS constellations (i.e. more than two hours apart and substantially different times of the day). The base receiver should reference a different primary project control monument for the

second session. If dual bases are used to reference two primary control monuments 100% of the following survey monuments shall be observed by a minimum of one RTK or PPK observation session from each base reference station (See [CDOT Class B – Secondary Horizontal Surveys](#), for additional information.)

- a. Property Boundary monuments
- b. Easement monuments
- c. Survey Alignment monuments

*Minimum verification of 68% of the above listed monuments may be increased to 100% by the Region Survey Coordinator.

Any reports required for GPS surveys needing federal approval shall be submitted to the correct federal agency for review and approval according to the agency's standards and procedures, and to the Region Survey Coordinator for review and filing in the region survey office records for the project.

GPS Operations Manual

3.1.8 Each Project Report will include a Region GPS Operating report for that project. The purpose is to establish equipment configuration settings and information sharing unique to the conditions for each Region or Project. Each region's manual report shall include but not be limited to the following:

1. CDOT GPS contact information / names
2. GPS technical support contact information preferably the Survey Project Manager or Vendor used for equipment maintenance.
3. GPS radio frequencies settings and FCC license information
 - a. Name of the Vendor for VRS networks and license information, if applicable
4. GPS equipment settings for various equipment configurations to perform the following GPS surveys:
 - a. Static
 - b. Fast Static
 - c. RTK
 - d. PPK

3.2 Error Sources in GPS

- [Best Practices for Minimizing Errors during GNSS Data Collection](#)
- [Foundation of Global Navigation Satellite Systems](#)
- [GNSS Positioning: Survey Planning and Data Acquisition](#)

General

Although measurement errors in GPS can never be completely eliminated, through proper planning, procedures, redundant checks, and repeat measurements errors can be isolated, identified and kept to a minimum.

3.2.1

Multipath

Multipath results from the interference of a GPS signal that has reached the receiver's antenna by two or more different paths, usually caused by one path being bounced or reflected off of a surface. The effects of multipath occurs at all GPS receivers used to perform the survey (*e.g.* base and rovers). While performing any GPS survey, multipath must be kept to a minimum at all receivers.

Sources of multipath include but are not limited to the following:

1. Mountains
2. Towers
3. Buildings
4. Bodies of water
5. Chain link fences
6. Vehicles
7. Signs
8. Snow
9. Ground surface
10. Overhead utility lines
11. Overhead Vegetation

The effects of multipath can be reduced by the following methods:

1. Be aware of your surroundings, do not set GPS points in areas with multipath.
2. Collect data for longer periods of time.
3. Collect data with multiple sessions with substantially different GPS constellations (*i.e.* substantial different times of the day, this is necessary since the satellite constellation geometry repeats itself every 12 hours.)
4. Move the base to a different primary control monument for RTK or PPK sessions.

5. Raise the elevation mask to get above the surface causing the multipath (most GPS processing software allows for the elevation mask to be raised while processing, but not lowered).

Ionosphere

- [NOAA GPS Dashboard](#)
- Weather and Solar flares: <https://www.swpc.noaa.gov/>

3.2.3 The ionosphere is a layer of the atmosphere filled with charged particles. Satellite signals passing through this layer of atmosphere are subject to ionospheric refraction resulting in a change in the speed of the GPS signal as it passes through the ionosphere.

The effects of the ionosphere for baseline lengths under 10 kilometers are almost equal to each other at both receivers, therefore ionospheric modeling is not necessary for processing of these baselines. For baseline lengths over 10 kilometers the ionosphere is not equal to each other at both receivers, therefore ionospheric modeling is necessary. Ionospheric modeling is accomplished by multi-channel tracking multi frequency receivers.

CDOT requires multi-channel tracking multi frequency receivers for all GPS surveys.

Positional Dilution of Precision (PDOP)

3.2.4 Satellite geometry is a numerically expressed number known as the PDOP and is caused solely by the geometry of the satellites in relation to the observer of those satellites. Proper satellite geometry is critical for accurate GPS measurements through the planning of GPS surveys to be performed during times of optimum satellite geometry. The use of multiple satellite constellations improves PDOP due to additional satellites and better geometry. GLONASS can introduce error in some cases and should not be included if High PDOP is an issue.

Equipment Error

3.2.6 Poorly maintained GPS equipment can introduce errors. Although not all error in GPS equipment can be completely eliminated, the error caused by GPS equipment shall be kept to a minimum by the scheduled maintenance checking, and calibration of GPS equipment on a continual basis.

Ephemeris Types (NGS)

A GPS ephemeris is the predictions of current satellite positions. Accurate GPS planning is only accomplished when a current ephemeris is used for the GPS planning.

Current ephemeris can be obtained by the following methods:

1. Downloading the ephemeris from the internet
2. Observing the satellites for a minimum of 15 minutes and downloading from the receiver

Type		Accuracy	Latency	Updates	Sample Interval
Broadcast	orbits	~100 cm	real time	—	daily
	Sat. clocks	~5 ns RMS ~2.5 ns SDev			
Ultra-Rapid (predicted half)	orbits	~5 cm	real time	at 03, 09, 15, 21 UTC	15 min
	Sat. clocks	~3 ns RMS ~1.5 ns SDev			
Ultra-Rapid (observed half)	orbits	~3 cm	3 – 9 hours	at 03, 09, 15, 21 UTC	15 min
	Sat. clocks	~150 ps RMS ~50 ps SDev			
Rapid	orbits	~2.5 cm	17 – 41 hours	at 17 UTC daily	15 min
	Sat. & Stn. clocks	~75 ps RMS ~25 ps SDev			5 min
Final	orbits	~2.5 cm	12 – 18 days	every Thursday	15 min
	Sat. & Stn. clocks	~75 ps RMS ~20 ps SDev			Sat.: 30s Stn.: 5 min

The satellite's orbit (navigation files) sent by the satellite's clock may be off by a few milliseconds and its position could be off by as much 20 meters. An Ultra-Rapid (observed half) ephemeris is calculated after the fact by several analysis centers around the world and is good to 3 centimeters. The Final ephemeris is typically available 12-18 days after the observations are completed.

For the final processing of CDOT Class A – Primary surveys a final ephemeris should be used.

3.2.7

National Geodetic Survey GPS Orbits

https://www.ngs.noaa.gov/orbits/orbit_data.shtml

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GPS Orbits

- Orbits Home
- Orbit Naming Convention
- Analysis Strategy
- Orbit Data
- Contact Us

GPS Orbit Data

IGS Product Information
SP3 Conversion (sp3c → sp3a)

Ultra-rapid (iguWWWWWD.sp3)
6-hour latency
constrained (no-net rotation, no-net translation) 24-hour file – sp3

Rapid (igrWWWWWD.sp3)
13-hour latency
constrained (no-net rotation, no-net translation) 24-hour file – sp3

Final (igsWWWWWD.sp3)
12 to 14 day latency
minimally constrained (no-net rotation) 24 hour file – sp3
files named by GPS Week number and Day of Week

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Human Error

- Sources of GNSS Errors
 - [Best Practices for Minimizing Errors during GNSS Data Collection](#)

The greatest contributor to error in GPS measurement is human error. Care must be taken while performing any GPS survey to keep human error to a minimum by proper procedures, redundant checks, repeat measurements and GPS observation log reports.

The following are some examples of human error:

1. Misreading antenna height measurements or measuring to incorrect reference point.
2. Transposing numbers entered electronically and/or on the GPS observation log
3. Rushing observations
4. Poor centering and leveling over points
5. Observing the wrong survey point (for example, observing a reference mark instead of the actual mark itself)
6. Incorrect equipment configuration settings

3.3 GPS Equipment Checking and Calibration

General

3.3.1 Checking and calibration of all types of survey equipment is essential to obtain and maintain the tolerances required in this chapter. At the beginning of any survey all survey equipment needed to perform the survey shall be checked and calibrated by the professional land surveyor in responsible charge of the survey under his/her direct supervision and/or checking.

A vendor's certificate of the last calibration adjustment is recommended and acceptable at the Region Coordinator discretion. Daily Survey field reports containing checks to passive NGS mark checks is recommended to show that the equipment is staying within acceptable tolerances as required in this manual. Errors due to poorly maintained or malfunctioning equipment will not be accepted. If any equipment errors are found to exist, they must be reported to the Region Survey Coordinator immediately. These errors will need to be verified and eliminated prior to performing any survey. For surveys lasting longer than 6 months, the checking and calibration of equipment shall be repeated

Checking and Calibration

3.3.2

Following are the types of checking and calibration of equipment that are accepted by CDOT:

1. Equipment Maintenance and adjustment
2. Existing CDOT Project Control Check
3. An authorized equipment vendor or manufacturer's service department calibration of GPS survey equipment.

3.3.3

Equipment Maintenance

At the beginning of any survey and once every 6 months thereafter, all necessary survey equipment needed to perform the survey shall be checked and adjusted by the professional land surveyor in responsible charge of the survey under his/her direct supervision and/or checking. All equipment shall be checked once every six months and as needed during the course of the survey, whichever comes first.

Checks and adjustments shall include but are not limited to those outlined in Calibration and Checking above and the following:

1. Tripods - nuts and bolts are tight, no loose or broken legs, tripod head is tight, flat, and not damaged.
2. Fixed Height Tripods - level bubbles are in adjustment, rod is not bent or damaged, height of rod is correct as reportedly measured, legs are secure.

3. Rods - level bubbles are in adjustment, rod is not bent or damaged, fittings are tight, height of rod is correct as reportedly measured, and adjustable rod height clamps are secure.
4. Tribrachs - optical plummets are in adjustment, level bubble is in adjustment, no loose legs, no loose or missing screws, bottom head is flat and not damaged.
5. Collimators - level bubble is in adjustment, top and bottom heads are both flat with no damage.
6. Cables - no cuts, breaks, pinch marks, or damage, including broken or bent pins.
7. Receivers - no cracks or visible signs of damage.
8. Receiver Antennas - if equipped with a ground plane it is not bent or warped, no cracks or visible signs of damage.

Federal Published Calibrated Baseline Check

3.3.4 The NGS conducts a cooperative program that provides surveyors with a means for calibrating and checking of errors in Electronic Distances Measuring Instruments (EDMI). Publications are available through NGS on the procedures for checking of EDMIs against a Federal Calibrated Baseline. The same procedures used for checking of EDMIs are adopted and used for checking of GPS equipment for Static, Fast Static, RTK, and PPK methods. The observed unadjusted baseline lengths shall meet or exceed the manufacturer's ratings for the equipment used when checked against a calibrated baseline both horizontally and vertically.

3.3.5

Existing CDOT Primary Control Check

While collecting data in either RTK or PPK mode, the checking of existing CDOT primary control monuments shall be completed to ensure the data being collected meets or exceeds the Minimum Horizontal and Vertical Accuracy Tolerances as required for the survey. This check is intended to serve as a quality control check during the survey and is not to be used in place of a calibrated baseline check. A primary control check report shall be submitted for all existing primary control checks (See section 3.1.7 this, Chapter for GPS Reports, for additional information). Primary control checks should be performed at the following times:

1. At the beginning of each survey session or new base position
2. During roving while initialized
3. Before ending the survey session

Primary control monument checks shall be performed as follows:

1. The RTK rover shall be placed on a primary control monument mark and leveled.
2. RTK data shall be collected with the same equipment configuration (*i.e.* elevation mask, epochs, sync time, maximum PDOP, satellite tracking, session duration, etc.) and methods that will be used for performing the survey.

3. The horizontal and vertical difference between the record primary control data and the collected RTK data shall be verified by either inverting the two locations or by use of an RTK stakeout mode that calculates and reports the difference within the data collector.
4. The horizontal and vertical difference shall be stored in the daily electronic field notes recorded for that day
5. The horizontal and vertical differences should meet or exceed the Minimum Horizontal and Vertical Accuracy Tolerances required for the survey or the RTK setup will be checked for errors and the process repeated.

3.4 GPS Survey Methods

23 CFR 630.402 - Geodetic

(a) Geodetic surveys along Federal-aid highway routes may be programmed as Federal-aid highway projects.

- 3.4.1 (b) All geodetic survey work performed as a Federal-aid highway project will conform to National Ocean Survey (NOS) specifications. NOS will, as the representative of FHWA, be responsible for the inspection and verification of the work to ascertain that the specifications for the work have been met. Final project acceptance by FHWA will be predicated on a finding of acceptability by NOS.

HARN Densification Surveys (HARND)

- 3.4.2 The following HARND standards and guidelines are available at the following web sites:

NGS/NOAA:

<https://www.ngs.noaa.gov/>

The above link provides information on NGS/NOAA home page.

3.4.3 Fast Static GPS Surveys

Fast Static survey methods shall be used for CDOT project control as an option to Static survey methods when the required Minimum Horizontal Accuracy Tolerance is for a CDOT Class A - Primary Horizontal or CDOT Class B - Secondary Horizontal Surveys. Fast Static surveys allow for systematic errors to be resolved when high accuracy positions are required by collecting simultaneous data between stationary receivers for a shorter period of time than that of Static surveys. For Fast Static surveys, observation times are typically 8 to 20 minutes and are determined at the time of the field survey by the number of satellites available. Fast Static survey methods allows for the creation of a GPS network in a “Leap Frog” pattern. Each baseline between adjacent intervisible control monuments along a transportation corridor must be observed at least twice.

Receivers must be capable of recording data for post processing. Multi-channel tracking multi-frequency receivers are required. Receivers and post processing software must be specified by the manufacturer to be suitable for high accuracy Fast Static surveys. The fast static horizontal and vertical accuracy tolerances specified by the manufacturer shall meet or exceed the CDOT Minimum Horizontal and vertical tolerances as required for the survey.

Fast Static equipment requirements:

1. Only adjustable leg tripods or fixed height tripods shall be used for any Fast Static survey. Fixed height tripods are preferred.
2. Whenever feasible, all antennas for the survey should be of the same make and model.
3. Antennas should have a ground plane in place for Fast Static surveys.
4. As a guideline CDOT recommends an epoch setting of 1 second and a sync time setting of 5 seconds for all Fast Static surveys.

RTK GPS Surveys

- [Best Practices for Minimizing Errors during GNSS Data Collection](#)

RTK survey methods shall not be used for any primary control survey project requiring CDOT 3.4.4 Minimum Horizontal Accuracy Tolerances for a CDOT Class A - Primary Horizontal Surveys.

RTK surveys are a “Radial” type survey that utilizes two or more receivers with at least one receiver remaining stationary over a known (reference or base station) project control monument. Other receivers (rovers) are moved from point to point collecting data in a short amount of time. Reference stations shall be of the same or higher accuracy as required for the RTK survey. RTK surveys measure the baselines from the reference station to the roving receivers’ point. A radio at the reference station broadcasts the position of the reference point to the rovers and the system processes the baselines in “Real Time” allowing for project coordinate information to be gathered and analyzed during the actual field survey.

Receivers must be capable of being connected to a radio at the reference station for broadcasting and to a radio at the rover for receiving the reference station broadcast. Multi-channel tracking multi frequency receivers are required. Receivers must be specified by the manufacturer to be suitable for RTK surveys. The RTK Horizontal and Vertical Accuracy Tolerances specified by the manufacturer shall meet or exceed the CDOT Minimum Horizontal and Vertical Accuracy Tolerances as required for the survey.

Care needs to be taken in the field to ensure that the RTK calibration, base station, and project control points have been set up correctly to allow the RTK data being collected to meet or exceed the CDOT Minimum Horizontal and Vertical Accuracy Tolerances as required for the survey. (See [Existing CDOT Primary Control Check](#), and [GPS Reports](#), for additional information).

Multipath at the reference station and at the rovers, re-initializations and loss of radio link must be kept to a minimum through project scheduling and organization of the “Best Use” survey method that should be used for the logistics of the survey project. It should be kept in mind that RTK surveys are just another tool available to complete a survey project and should only be used only when the CDOT Minimum Horizontal and Vertical Accuracy Tolerances as required for the survey can be met or exceeded.

As a guideline CDOT recommends an epoch setting of 1 second.

VRN may be used for RTK surveys with the approval of the Region Survey Coordinator. See [Virtual Reference Network \(VRN\)](#) for more information.

RTK Site Calibrations

When the project coordinate system is an Earth Centered Earth Fixed (ECEF) system, CDOT recommends using the defined projection, datums and modification factors over a site calibration as a direct way to check the coordinate system. Calibrations may obscure inappropriate distortions in the coordinate system parameters and should only be used for flat plane, assumed coordinate systems, which are not typically used for CDOT projects.

RTK site calibration establishes the relationship between the latitude, longitude, and ellipsoid height (geodetic) observed with GPS and the final adjusted local project control northing, easting, and differential leveled elevation (local project control) for each point. The relationship between these coordinate systems is defined by a series of mathematical parameters. Conversions are applied during the calibration through a process of least squares that allows for future geodetic positions determined by GPS observations to be converted to local project control coordinates.

The site calibration is performed to obtain the parameters that allow for the conversion from geodetic coordinates to local project control coordinates and back again within the data collector in real time. The local project control coordinate values of the control points are used in the calibration to generate residuals of the GPS derived observations. The GPS derived coordinates will not be used because known local project control values already exist for the control points and remain fixed.

To perform a site calibration a minimum of 3 horizontal control points are required, a minimum of 5 horizontal control points are recommended for redundancy. Each of these horizontal control points must have geodetic positions that were observed by either a GPS Static or Fast Static network, as well as having final adjusted project control coordinate values. To perform a vertical calibration at least 4 vertical control points are required, a minimum of 5 vertical control points are recommended for redundancy. The vertical calibration is the last part of the calibration to be computed. The vertical calibration makes the GPS derived orthometric heights (GPS derived elevations) match as closely as possible with the control differential elevations. (See [GPS Derived Orthometric Heights \(Elevations\)](#), for additional information).

The site calibrations consist of the following horizontal conversion parameters:

1. Rotation – All of the horizontal points in the calibration are used to calculate the centroid (geographic center) about which a rotation of all horizontal GPS points are rotated by the same angular amount.
2. Translation – All of the horizontal points in the calibration have their geodetic positions moved in the same direction and the same distance so they will match closer to the final local project control coordinates.

3. Scale – A scale factor is calculated using a ratio of the true distances between the local project control coordinates, and the distances calculated between the GPS derived geodetic positions for the same points. This ratio is the scale factor.

Once the above conversion parameters have been determined and a best fit of the observed GPS derived geodetic positions with the local project control coordinates has been calculated, minor discrepancies between the GPS derived geodetic positions and the local project control coordinates will still exist. These discrepancies are called the “Residuals” and should be relatively small. The residuals are very helpful in deciding whether the site calibration is satisfactory or not. In addition, PPM error should also be evaluated in order to detect issues with an inclined plane. It is recommended that these residuals be no larger than the accuracy tolerance of the Static or Fast Static control survey that was performed for the control points and shall not exceed the accuracy tolerance for the RTK survey being performed.

As a guideline CDOT recommends running the calibration initially with a scale factor of one (1) to detect potential discrepancies with the scaling of the control coordinates.

PPK GPS Surveys

- 3.4.6 PPK survey methods shall not be used for any survey project requiring CDOT Minimum Horizontal Accuracy Tolerances for a CDOT Class A – Primary survey.

PPK surveys are a “Radial” type survey similar to an RTK survey, however there is no radio at either the reference station or the rover to broadcast and the system does not process the baselines in real time. PPK utilizes two or more receivers with at least one receiver remaining stationary over a known (reference or base station) project control monument. Other receivers (rovers) are moved from point to point collecting data in a short amount of time. Reference stations shall be of the same or higher accuracy as required for the PPK survey. PPK surveys measures the baselines from the reference station to the roving receivers. Data is collected at both the reference station and at the rover receivers. The data is downloaded into a GPS processing software program to process the baselines.

Receivers must be capable of collecting data at the reference station and at the rover for downloading into a GPS processing program. Multi-channel tracking multi frequency receivers are required. Receivers must be specified by the manufacturer to be suitable for PPK surveys. The PPK Horizontal and Vertical Accuracy Tolerances specified by the manufacturer shall meet or exceed the CDOT Minimum Horizontal and Vertical Accuracy Tolerances as required for the survey.

Care needs to be taken in the field to ensure that the PPK calibration, base station, and project control points have been set up correctly to allow the PPK data being collected to meet or exceed the CDOT Minimum Horizontal and Vertical Accuracy Tolerances as required for the survey. (See [Existing CDOT Primary Control Checks](#), and [GPS Reports](#), for additional information).

Multipath at the reference station and at the rovers must be kept to a minimum through project scheduling and organization of the “Best Use” survey method that should be used for the

logistics of the survey project. It should be kept in mind that PPK surveys are just another tool available to complete a survey project and should only be used only when the CDOT Minimum Horizontal and Vertical Accuracy Tolerances as required for the survey can be met or exceeded.

A critical technique of the PPK survey is to avoid roving in environments where the number of satellites drops and “initialization” may be lost. The operator must be aware of loss off initialization and not collect data between initialization losses that will not allow for post processing to achieve a fixed solution.

As a guideline CDOT recommends an epoch setting of 1 second and a sync time setting of 5 seconds for all PPK surveys.

GPS for GIS Mapping Grade Surveys

3.4.7 GIS mapping grade receivers shall not be used to meet any CDOT Horizontal or Vertical Accuracy Tolerance for a CDOT Class A - Primary, CDOT Class B – Secondary, CDOT Class C - TMOSS or CDOT Class D - TMOSS survey. A GIS mapping grade receiver is defined for CDOT use as one that is unable to produce a post processed result within a horizontal accuracy tolerance of 0.050 meters at a ninety five percent (95%) confidence level. Available GIS databases can be accessed at: <https://cdot.maps.arcgis.com/home/groups.html> and on OTIS at <https://www.codot.gov/safety/safetydata/online-transportation-information-systems-otis>.

3.5 Static and Fast Static Network Design

3.5.1 Required Existing Control Monumentation

As stated earlier, GPS surveys for all CDOT projects shall be referenced and tied into the HARN. All existing control monumentation used to reference or “Tie In” the survey shall be of the same or higher accuracy as required for the survey.

A minimum of three existing horizontal control monuments shall be used to reference the survey, five are recommended for redundancy. These existing horizontal control monuments should be located outside the survey project area to encompass the entire project and provide for good network geometry throughout the network project area.

A minimum of one existing NAVD88 control monument shall be used to reference the survey, four are recommended for redundancy. If feasible, the existing vertical control monuments should be located in all four quadrants of the survey and encompass the entire project.

Network Geometry

A network consists of a set of baselines between network points. Networks can be described as having the following network design:

- 3.5.2
1. Good Network Geometry – A network design that allows for the network to have computed loop closures around small closed figures. If the loop misclosure is high, it indicates that there is a problem with at least one of the baselines in the loop. Good network geometry allows other loop closures to be done that identify and isolate problematic baselines in order that they can be easily removed.
 2. Bad Network Geometry – A network design that allows for loop closers to be computed that will show a problem exists within the network but does not allow the problematic baselines to be identified, isolated and removed.
 3. Poor Network Geometry – A network design that allows for coordinates to be computed for the unknown points but does not identify any errors that may exist in the network. This will result in baseline errors going undetected and propagating through the rest of the network.

All GPS networks shall be designed with good network geometry.

- For highway corridor control networks that are geometrically long and narrow, it is recommended that control network points be established outside of the highway corridor on monumentation such as Public Land Survey System (PLSS) monuments to strengthen the overall network geometry. Permission to Enter Property Forms shall be completed if required. Once these control network points have been incorporated into the control network survey they can then be used during RTK calibrations to strengthen the RTK calibration without the need to re-occupy the monument.
- 3.5.3

Redundancy of Networks

Redundancy provides for quality control checks of a network and also provides for the desired confidence in the results obtained from the survey. Each network shall be designed to have a sufficient amount of redundancy built into the network in accordance with the methods and procedures as required in this chapter to detect and isolate blunders and/or errors.

Redundancy of a network is achieved by the following:

1. Establish a minimum of four horizontal and vertical primary control monuments for each project encompassing the entire project.
2. Good network geometry built throughout the entire network
3. A minimum of two independent baselines between each control monument

4. Interconnecting closed loops
5. Repeat baselines measurement

Independent (Non-Trivial) Baselines

Static and Fast Static networks shall be designed as to process at a minimum two independent (non-trivial) baselines (vectors) between each adjacent control monument. For each session of simultaneous observations there is one less independent baseline than there are receivers.

3.5.4

An example is given for a control network consisting of four control monuments (CM) observed with three receivers. There must be five sessions to allow for two independent baselines to be measured between each control monument. Notice that for each session the receivers are moved to a different control monument, this allows for additional redundancy to be built into the network.

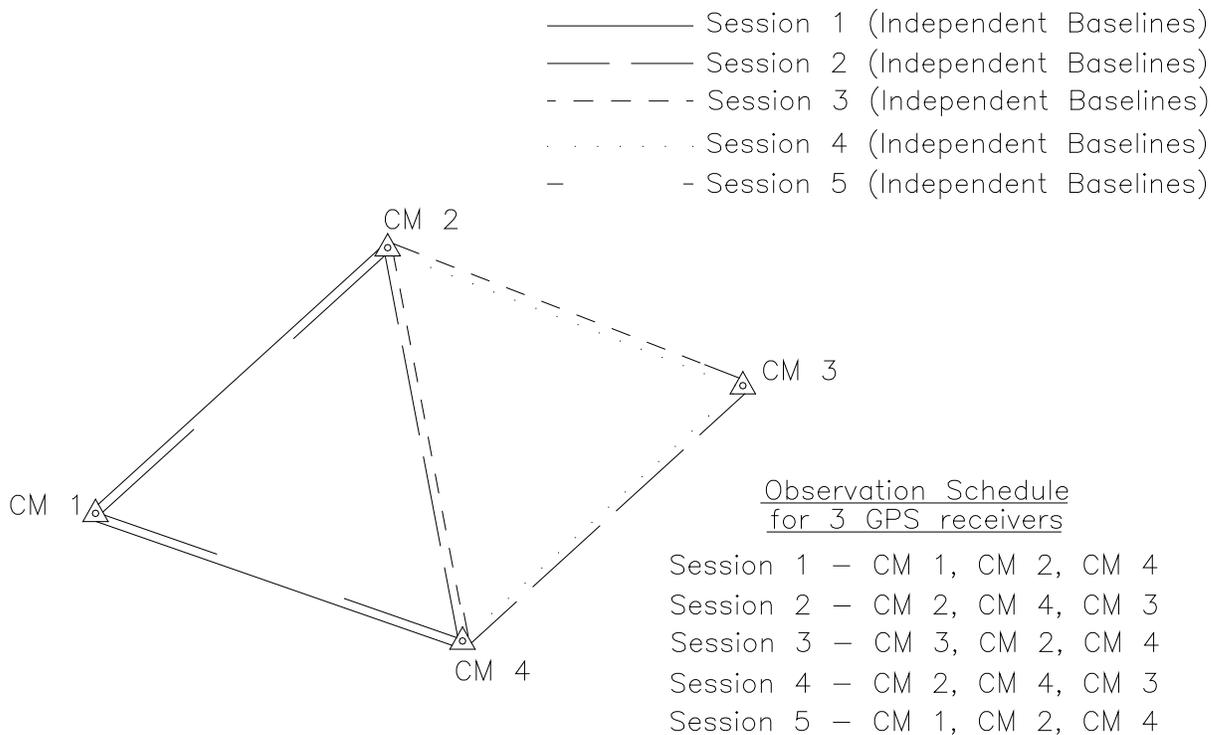


Figure 3 – 1

Network Loops

Networks shall contain only closed loops. A closed loop is a series of at least three independent connecting baselines that start and end on the same point with each loop having at least one baseline in common with another closed loop to prevent a break in the network. Closed loops shall include observed baselines from at least two observation sessions.

3.5.5

Twenty Percent Rule

For any two control monuments where the distance between the two control monuments is less than 20% of the total distance as measured along a series of closed connected loops to connect the two control monuments, there should be at least two independent baselines measured between the two control monuments.

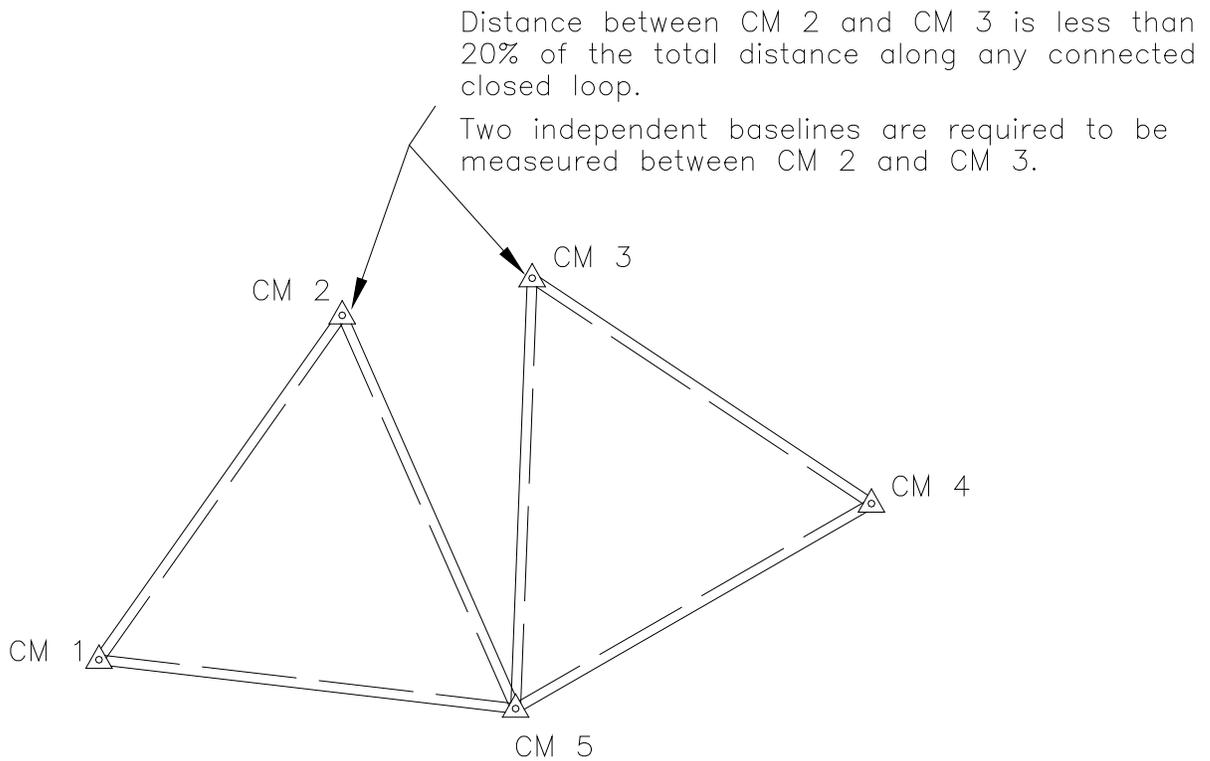


Figure 3 – 2

3.6 GPS Planning

Control Monumentation Site Selection

3.6.1 It is critical that before setting any control monumentation the project needs are identified. This is typically done through the initial scoping of the project to determine the projects limits, factors, and requirements. After the scoping has been completed the project surveyor shall identify areas to install CDOT Type 2 control monuments. The following considerations should be taken into account when choosing a site for installing control monumentation:

1. Sites should be free of vertical obstructions blocking the horizon such as buildings, overhangs, terrain, trees, fences, utility poles, overhead lines, or any other visible obstructions, non-obstructed skies 15 degrees above the horizon is best.
2. Sites located close to radio transmitters including cellular phone equipment may disrupt satellite signal reception.
3. Sites close to large flat surfaces such as signs, fences, glass, or utility boxes should be avoided.
4. Sites shall provide direct line of site between adjacent control monuments if possible.
5. Sites shall not exceed 0.6 mile between adjacent intervisible control monuments.
6. Establish a minimum of four primary control monuments encompassing the site for each project.
7. If feasible, sites should not be disturbed by future construction activities and should be outside the design toe of slopes and top of cuts for the project.
8. Sites shall be located within existing public Rights-of-Way.
9. If a site is located outside existing public Rights-of-Way Permission to Enter Property Forms shall be completed and an easement for access, installation, and maintenance of the control monument shall be acquired in CDOT's name for the benefit of the public for the purpose of performing a land survey.
10. Safety of sites shall be considered to avoid vehicular traffic, fall hazards, chemical hazards, steep/unstable slopes, electrical hazards, poisonous flora, dangerous animals or insects and other hazards as much as possible.
11. Sites should be on stable slopes and soils away from erosion. Soils that heave or subside should be avoided if possible. Corrosive soils should also be avoided.
12. Sites should be well drained to avoid ponding and ice buildup.

After the monumentation sites are identified for installation each site shall be marked and utility locates called for. (See Chapter 2 – General Procedures, Underground Utility Locates Prior to Installing Monumentation, for additional information.)

Ephemeris

A GPS ephemeris is the predictions of current satellite positions. Accurate GPS planning is only accomplished when a current ephemeris is used for the GPS planning.

3.6.2 Current ephemeris can be obtained by the following methods:

1. Downloading the ephemeris from the internet
2. Observing the satellites for a minimum of 15 minutes and downloading from the receiver

Refer to [Ephemeris](#) for information on ephemeris types

https://www.ngs.noaa.gov/orbits/orbit_data.shtml

The above link provides information and downloads to obtain a current ephemeris almanac. Most software applications now offer direct access to orbit data through their platforms.

Satellite Geometry

3.6.3

A minimum of four satellites are required to survey with GPS. A minimum of five satellites is recommended. The configuration of the visible satellites the receiver is able to track in relation to each other will make a significant difference in the data that is being collected. Satellite geometry is expressed as a numeric value known as Dilution of Precision (DOP). Good satellite geometry will have small DOP values while poor satellite geometry will have large DOP values. As a guideline DOP values of six or lower are recommended for CDOT GPS surveys. The ideal satellite geometry is one which has the visible satellites distributed throughout the sky. Good satellite geometry will yield a higher precision.

Satellite geometry factors that must be considered when planning a GPS survey are:

1. Number of satellites available
2. Minimum elevation angle above the horizon (elevation mask)
3. Obstructions limiting satellite visibility
4. Position Dilution of Precision (PDOP)
5. Vertical Dilution of Precision (VDOP)
6. Horizontal Dilution of Precision (HDOP)

United States Coast Guard, Navigation Center:

<http://www.navcen.uscg.gov/>

Or call for a 24 hour recorded message: 1-703-313-5907

The above link provides satellite information and important messages for all GPS users.

Elevation Mask

An elevation mask is the lowest elevation above the observer's horizon that a satellite's data is recorded. Most obstructions below a set elevation mask can be ignored, however multipath can still be produced from a surface below the set elevation mask. Elevation mask also help to minimize the atmospheric noise in the data. Satellites that are high in the sky will have less atmospheric noise than satellites low in the sky and very close to the observer's horizon. By having an elevation mask set, the noise in the GPS satellite signals is kept to a minimum. Most GPS processing software allows for the elevation mask to be raised while processing, but not lowered.

As a guideline CDOT recommends an elevation mask setting of 15 degrees for all GPS surveys.

Weather Conditions

3.6.5 Generally, weather conditions do not affect GPS surveying, however the following conditions must be considered when planning a GPS survey:

1. GPS Observations should never be conducted during an electrical storm.
2. Significant changes in weather or unusual weather conditions should be noted either in the field notes, data collector, or receiver.
3. Horizontal and vertical GPS observations can at times be affected by severe snow, hail and rainstorms, high accurate GPS surveys should not be conducted during these periods.
4. Sunspots or magnetic storms can affect GPS observations, care needs to be taken to avoid GPS surveying during these periods.
5. Tripods should be weighted or moored during high wind conditions
6. Caution should be used when setting up setting a tripod on frozen ground when above freezing temperatures are expected during the day. In those cases, it is recommended to set hubs for the legs and pack the feet in snow if possible.

NOAA Space Weather Now:

<https://www.swpc.noaa.gov/communities/space-weather-enthusiasts>

The above link provides information for space weather activities and warnings.

NGS GPS Calendar

<http://www.ngs.noaa.gov/CORS/Gpscal.shtml>

The above link provides information along with current and past GPS calendars.

3.7 GPS Vertical Procedures

Antenna Height Measurement

Blunders in antenna height measurements are a common source of error in GPS surveys. All GPS surveys are three-dimensional whether the vertical component will be used or not and care needs to be taken during any GPS survey when measuring the antenna height. Antenna height measurements determine the height from the survey monument mark to the phase center of the GPS antenna.

There are three types of antenna height measurements done for CDOT GPS surveys:

1. Fixed height tripod rods - To be used for Static, Fast Static, RTK, and PPK surveys. Preferred over adjustable height tripods for Static and Fast Static surveys.
2. Adjustable height tripods - To be used for Static, Fast Static, RTK, and PPK surveys.
3. Adjustable height rods - To be used only for RTK and PPK surveys.

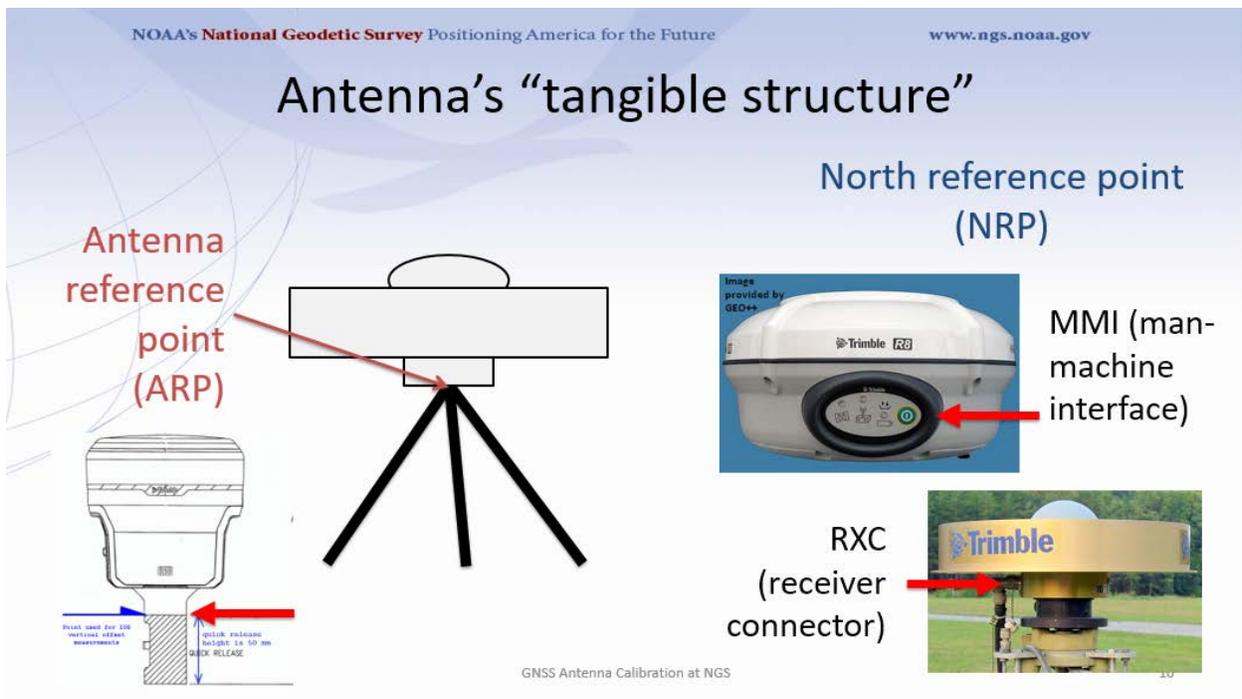


Figure 3 – 3

How is the antenna height measured?



ARP

The height is measured vertically (NOT the slant height) from the mark to the ARP of the antenna.

The height is measured in meters.

The ARP is almost always the center of the bottom-most, permanently attached, surface of the antenna.

See GPS Antenna Calibration for photo's and diagrams that show where the ARP is on most antennas.

If 0.0000 is entered for the height, OPUS will return the position of the ARP.

MARK

Also see <https://geodesy.noaa.gov/ANTCAL/index.xhtml> then, Browse Antenna Information by Company Brand and Model

Fixed height tripod rod antenna height measurement procedures:

1. The length of fixed height tripod rods shall be verified each day prior to the beginning of any observation sessions.
2. Care needs to be taken to ensure the correct antenna type, antenna height measurement type, and antenna height measurements are entered into the data collector correctly.
3. The following is recorded on the observation log sheet for each observation setup:
 - a. Antenna type
 - b. Antenna height measurement type
 - c. Antenna height measurement in both meters and feet
4. When downloading the data into a GPS post processing software program the following shall be verified for each observation session:
 - a. Antenna type
 - b. Antenna height measurement type
 - c. Antenna height measurement in both meters and feet

Adjustable height tripod antenna height measurement procedures:

1. The tripod is setup over the survey monument mark and leveled using a precision level prior to the observation session.
2. The mean of the three antenna height measurements is calculated and recorded on the observation log sheet.
3. The antenna height measurement is directly measured again in feet and recorded on the observation log sheet.
4. The mean of the antenna height measurement in meters is verified by comparing the measurement recorded on the observation log sheet in feet. The two shall not vary by +/- 0.02 feet or the antenna height shall be re-measured.
5. Care needs to be taken to ensure the correct antenna type, antenna height measurement type and the mean antenna height measurement is entered into the data collector correctly.
6. The following is recorded on the observation log sheet for each observation setup:
 - a. Antenna type
 - b. Antenna height measurement type
 - c. Three antenna height measurements in meters
 - d. Calculated mean antenna measurement in meters
 - e. Antenna height measurement in feet
7. When downloading the data into a GPS post processing software program the following shall be verified for each observation session:
 - a. Antenna type
 - b. Antenna height measurement type
 - c. Mean antenna height measurement is within +/- 0.02 feet of the measurement recorded on the observation log sheet in feet.

Adjustable height rods antenna height measurement procedures:

1. The length of adjustable height rods including the distance for the addition of the antenna shall be verified each day prior to the beginning of any observation sessions.
2. For adjustable height rods that are graduated either in meters, feet, or both, the graduations shall be verified that the height reading of the rod includes the correct distance for the addition of the antenna.

3. Adjustable height rods shall be checked continually for loose rod height clamps and tightened as necessary to avoid the rod height from slipping during the duration of the survey (See [Equipment Maintenance](#), for additional information).
4. Care needs to be taken to ensure that any changes made in the height of the adjustable height rod is entered into the data collector and that the correct antenna type, antenna height measurement type and antenna height measurement is entered into the data collector correctly.
5. When downloading the data from a PPK survey into a GPS post processing software program the following shall be verified for each observation session:
 - a. Antenna type
 - b. Antenna height measurement type
 - c. Antenna height measurement in both meters and feet

When a station is occupied during two or more back-to-back observation sessions without the equipment moving to another point, the entire antenna tripod setup shall be taken down, re-setup and re-leveled for each new observation session.

For stations that are occupied during two or more observations session with the tripod remaining stationary for the point but with new equipment being used for the observation session (such as antennas and receivers) the legs of the tripod shall be broken down and the setup re-leveled for an antenna height substantially different than that of the previous antenna height for each new observation session.

Rover rods shall not be used for any Static or Fast Static survey.

3.7.2

GPS Derived Orthometric Heights (Elevations)

GPS is a three-dimensional system and errors in the vertical component of GPS measurements will affect the horizontal positions. Due to this fact all GPS surveys for any type of CDOT survey shall measure the vertical component even if the vertical is not a requirement for the survey. GPS derived orthometric heights (elevations) are compiled from ellipsoid heights as determined by GPS observations and modeled geoid heights using the appropriate geoid model for the horizontal datum and adjustment.

In order to convert elevations from GPS into ground elevations it is necessary to apply geoid height corrections as depicted by the geoid model for the area of interest. The NGS is the primary source for defining and maintaining geoid models. NGS updates geoid models on a 3-year cycle (*e.g.* GEOID09, GEOID12B, GEOID18).

NGS Geoid Page

<http://www.ngs.noaa.gov/GEOID/>

The above link provides downloads for the latest NGS/NOAA approved geoid models.

NGS Geodetic Tool Kit

<http://www.ngs.noaa.gov/TOOLS/>

The above link provides downloads for the latest NGS/NOAA tools.

NOAA Guidelines for Establishing GPS-Derived Orthometric Heights Technical Memorandum Version 4.3:

http://www.ngs.noaa.gov/PUBS_LIB/NGS-58.html

The above link provides information and guidelines for establishing GPS derived ellipsoid heights.

Because of distortions in vertical control networks, lack of high accuracy benchmarks and limitations in the geoid height models, GPS derived orthometric heights can be difficult to validate. Errors in GPS derived heights will generally be +/- three times worse than the horizontal errors. However, comparable results between GPS derived heights and elevations obtained directly by differential leveling techniques are obtainable and for now is the best way to determine the accuracies of the vertical component in GPS measurements.

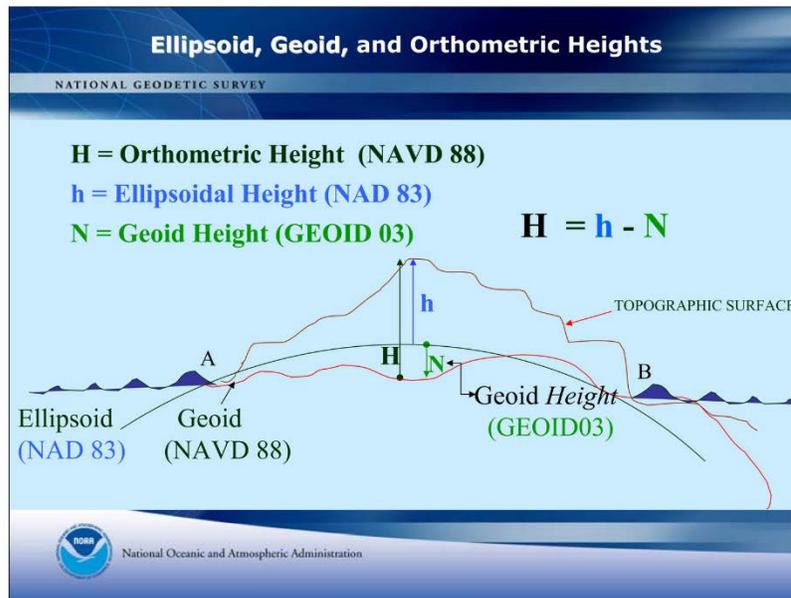


Figure 3 – 4

Due to the fact that highway corridors have GPS control networks established on the ground with GPS control monuments spaced a maximum distance of 0.6 mile that have latitudes, longitudes, ellipsoid heights and differential leveled elevations, a geoid model is not required to be imported into an RTK systems data collector to obtain GPS derived orthometric heights while performing an RTK survey inside a control network, however it is recommended (See [GPS Reports](#), for additional information). If no geoid model is used the undulation of the geoid with respect to the ellipsoid is resolved to produce a simple planar geoid model for the project area. By using the

latest geoid model available the GPS derived heights will be related to the geoid resulting in elevations that will better fit the Earth's surface.

If accurate elevations are needed outside the control network a differential level loop should be ran to provide control and checks of the vertical component.

For additional information see [NGS National Height Modernization Program \(NHMP\)](#) in this chapter or check the NGS website at <https://geodesy.noaa.gov/heightmod/About.shtml#:~:text=National%20Height%20Modernization%20Program,and%20modern%20remote%20sensing%20information.>

CDOT Class A – Primary Vertical Surveys

All CDOT Class A – Primary vertical surveys performed with GPS shall be performed in accordance with the methods and procedures as required in this chapter either for a Static or Fast Static survey meeting the Minimum Vertical Accuracy Tolerance for a CDOT Class A - Primary Survey (See Chapter 5 – Preliminary Surveys, for additional information).

For any CDOT Class A – Primary vertical survey or any primary control monument that requires accurate elevations be obtained beyond the GPS equipment manufacturer's stated vertical accuracy tolerance, differential leveling shall be used to obtain NAVD88 elevations by the methods, procedures, and Minimum Vertical Accuracy Tolerance as required in Chapter 5 – Preliminary Surveys of this manual.

Unless approved otherwise by the Region Survey Coordinator no CDOT Class A - Primary vertical survey or primary control monument that requires accurate elevations shall have the elevations established by GPS derived heights. GPS may be used to seed an initial elevation for a project on a single point if no NGS benchmarks exist within a reasonable proximity to the project. In this situation the seed elevation should be derived from an OPUS solution.

For post processing of any CDOT Class A - Primary vertical survey or any Static or Fast Static survey, a minimally constrained adjustment shall be completed by holding fixed only one three-dimensional control mark having a published Latitude, Longitude, ellipsoid height and a NAVD88 elevation of the either the same or higher accuracy than that of the survey being performed. The minimally constrained adjustment shall verify that the vertical component for the ellipsoid heights are within an acceptable tolerance for the survey at the ninety five percent (95%) confidence level, or the survey data shall be checked for blunders, errors and corrected.

Once the minimally constrained adjustment is at an acceptable accuracy tolerance level as required for the survey, a current geoid model shall be imported into the software and the geoid separations calculated. A fully constrained adjustment is then performed by incorporating and holding fixed only one additional differential leveled vertical control mark at a time. For each vertical control mark that is added and held fixed, the entire network shall be re-adjusted and verified to be within an acceptable vertical tolerance level for the survey by comparing the GPS derived orthometric heights to the differential leveled elevations. This process is repeated as

many times as needed until all differential leveled vertical control marks have been incorporated into the survey and are held fixed.

CDOT Class B – Secondary Vertical Surveys

All CDOT Class B – Secondary vertical surveys performed with GPS shall be performed in accordance with the methods and procedures as required in this chapter either for a Static, Fast Static, RTK or PPK survey meeting the Minimum Vertical Accuracy Tolerance for a CDOT

3.7.4 Class B - Secondary survey (See Chapter 5 – Preliminary Surveys, for additional information).

For survey monuments that require accurate elevations be obtained beyond the GPS equipment manufacturer’s stated vertical accuracy tolerance, 100% of all GPS derived elevations shall be verified or supplemented with elevations by a more accurate survey method as follows:

1. Differential leveled elevations in accordance with the methods and procedures as required in Chapter 5 – Preliminary Surveys.
2. Trigonometric elevations by conventional survey methods such as a total station in accordance with the methods and procedures as required in Chapter 5 – Preliminary Surveys.

CDOT Class C – TMOSS Vertical Surveys

3.7.5

All CDOT Class C – TMOSS vertical surveys performed with GPS shall be performed in accordance with the methods and procedures as required in this chapter either for a Static, Fast Static, RTK or PPK survey meeting the Minimum Vertical Accuracy Tolerance for a CDOT Class C – TMOSS survey (See Chapter 5 – Preliminary Surveys, for additional information).

For TMOSS locations that require accurate elevations be obtained beyond the GPS equipment manufacturer’s stated vertical accuracy tolerance, 100% of all GPS derived elevations shall be verified or supplemented with elevations by a more accurate survey method as follows:

1. Trigonometric elevations by conventional survey methods such as a total station in accordance with the methods and procedures as required in Chapter 5 – Preliminary Surveys.

3.7.6

2. Differential leveled elevations in accordance with the methods and procedures as required in Chapter 5 – Preliminary Surveys.

CDOT Class D – TMOSS Vertical Surveys

All CDOT Class D – TMOSS vertical surveys performed with GPS shall be performed in accordance with the methods and procedures as required in this chapter either for a Static, Fast Static, RTK or PPK survey meeting the Minimum Vertical Accuracy Tolerance for a CDOT Class D – TMOSS survey (See Chapter 5 – Preliminary Surveys, for additional information).

For TMOSS locations that require accurate elevations be obtained beyond the GPS equipment manufacturer's stated vertical accuracy tolerance, 100% of all GPS derived elevations shall be verified or supplemented with elevations by a more accurate survey method as follows:

1. Differential leveled elevations in accordance with the methods and procedures as required in Chapter 5 – Preliminary Surveys.
2. Trigonometric elevations by conventional survey methods such as a total station in accordance with the methods and procedures as required in Chapter 5 – Preliminary Surveys.

Primary Control Benchmark Procedures using GPS/GNSS

Chapter 5, Section 5.9.6 currently states:

3.7.7 The following Minimum Vertical Accuracy Tolerance shall apply to all CDOT Class A – Primary control benchmarks and surveys, and all CDOT Class B – Secondary control benchmarks and surveys:

In feet, the square root of the total horizontal distance of the differential level loop in miles multiplied by 0.035 feet. [$0.035 \text{ ft } \sqrt{d} \text{ miles}$]

The results of this evaluation shall be recorded in the field book for each differential level loop. At least two established benchmarks on the same or mathematically related datum shall be used to verify that the starting mark has not been disturbed. No adjustments of the data used for this evaluation will be allowed.

Advances in Technology:

New technology (GPS/GNSS) makes it more efficient and effective to establish a primary control benchmark. Often NGS vertical control is not readily available within the project area, thus the new procedures allow for establishing a vertical height easily, efficiently, and economically using GPS/GNSS. There are three recommended methods of establishing a primary control benchmark: OPUS, Fast Static and Real Time Networks (RTN). These methods are described below.

Use of these methods need prior approval by the CDOT Survey Coordinator.

Recommended New Primary Control Benchmark Procedures using OPUS (Online Positioning User Service)

Select a project control point and use vertical data derived from 120-minute minimum GPS observation processed through OPUS as your primary control benchmark. Verify OPUS results meet the quality standards as stated below. Use the OPUS determined orthometric height as the primary control benchmark. Level from this height through the project control following recommended leveling procedures identified in Chapter 5 of the CDOT Survey Manual.*

** Time is dependent on achieving your quality standards as listed below*

Recommended CDOT OPUS Quality Standards
Fixed Height Tripod Recommended (If not used, requires prior approval of CDOT Survey Coordinator)
Orbit used = precise or rapid;
> 90% observations used;
> 80% ambiguities fixed;
Correct antenna and antenna height;
Overall RMS < 3 cm, peak to peak errors < 3 cm

Recommended New Primary Control Benchmark Procedures using Fast Static

Select a project control point and use vertical data derived from a Fast Static survey as your primary control benchmark. Fast Static control network should include a minimum of two existing NGS benchmarks of second order or greater. Verify your Fast Static results meet the quality standard below. Level from this height through the project control following recommended leveling procedures identified in Chapter 5 of the CDOT Survey Manual.

Recommended CDOT Quality Standard
*0.04 m (0.13 ft) vertical, 95% confidence interval ***

Recommended New Primary Control Benchmark Procedures using RTN

Select a project control point and collect data for 3 observations throughout the day (for example one in the AM, one mid-day and one in the PM) each for three minutes within the network and verify they are within the positional tolerance of the respective CDOT accuracy class necessary for the control point. If the observations are within tolerance, average the 3 observations to obtain the final positions for the primary control benchmark. Level from this height through the project control following recommended leveling procedures identified in Chapter 5 of the CDOT Survey Manual.

Recommended CDOT Quality Standard
0.04 m (0.13 ft) vertical, 95% confidence interval

Quality Assurance Control Points

Additional vertical control points may be set at the discretion of the Survey Coordinator for the purpose of verifying leveling data and eliminating the need to close the project control level loop back to the primary control benchmark. Leveled data tolerance must not exceed the criteria below. These points would be set using the methods described above and at an interval of not less than one mile. The elevation provided on the project control diagram should be derived from the leveled data.

In feet, the square root of the total horizontal distance of the differential level loop in miles multiplied by 0.035 feet. [0.035 ft \sqrt{d} miles]

OPUS-on-Benchmarks

If feasible, setup over a known NGS control station and collect at least 4 hours of GPS/GNSS data. Submit the data, two photos (one of the mark and one showing the mark in its surroundings), antenna height and type through OPUS-Share. Preferred NGS control is a 1st or 2nd order leveled NAVD88 benchmark.

3.8 GPS Horizontal Procedures

Minimum Horizontal Accuracy Tolerance Table

All GPS surveys for CDOT shall meet the Minimum Horizontal Accuracy Tolerance Table as shown Chapter 5 – Preliminary Surveys of this manual, for either a CDOT Class A – Primary, Class B – Secondary, Class C - TMOSS, or Class D - TMOSS Horizontal Surveys.

3.8.1

CDOT Class A – Primary Horizontal Surveys

3.8.2 All CDOT Class A – Primary horizontal surveys performed with GPS shall be performed in accordance with the methods and procedures as required in this chapter for either a Static or Fast Static survey meeting the Minimum Horizontal Accuracy Tolerance for a CDOT Class A – Primary Horizontal Surveys (See Chapter 5 – Preliminary Surveys, for additional information).

No RTK or PPK survey shall be performed for any CDOT Class A - Primary Horizontal Surveys.

For the final processing of any CDOT Class A – Primary Horizontal Survey a precise ephemeris should be used. (See [Ephemeris Types \(NGS\)](#), for additional information).

3.8.3 Final adjusted horizontal project control coordinates and ground distances between 68% of all directly connected intervisible adjacent control monuments should be verified to be within the Minimum Horizontal Accuracy Tolerance for a CDOT Class A – Primary Horizontal Surveys by conventional survey methods such as a total station with an electronic distance meter. (See [GPS Reports](#), for additional information.)

CDOT Class B – Secondary Horizontal Surveys

All CDOT Class B – Secondary Horizontal Surveys performed with GPS shall be performed in accordance with the methods and procedures as required in this chapter either for a Static, Fast Static, RTK or PPK survey meeting the Minimum Horizontal Accuracy Tolerance for a CDOT Class B – Secondary Horizontal Survey (See Chapter 5 – Preliminary Surveys, for additional information).

Final RTK or PPK project coordinates for 100% of the following survey monuments shall be verified (See [GPS Reports](#), for additional information) to be within the Minimum Horizontal Accuracy Tolerance for a CDOT Class B – Secondary Horizontal Survey by observing each survey monument with a minimum of two independent RTK or PPK observation sessions (*i.e.* two separate initializations) with substantially different GPS constellations (*i.e.* more than two hours apart and on substantially different times of the day). The base receiver should reference a different primary project control monument for the second session. If dual bases are used to reference two primary control monuments 100% of the following survey monuments shall be observed by a minimum of one RTK or PPK observation session from each base reference station:

1. Secondary Control monuments
2. Photo Control monuments (center and wing points) *
3. Public Land Survey System monuments
4. Right-of-Way monuments
5. Etc.

* Unless approved otherwise by the Region Survey Coordinator all GPS Photo Control monuments (center and wing points) shall be observed only by Static or Fast Static survey methods and procedures in accordance with this chapter. (See Chapter 4 – Aerial Surveys, for additional information.)

Final RTK or PPK project coordinates for a minimum of 68%* of the following survey monuments shall be verified (See [GPS Reports](#), for additional information) to be within the Minimum Horizontal Accuracy Tolerance for a CDOT Class B – Secondary Horizontal Survey by observing each survey monument with a minimum of two independent RTK or PPK observation sessions (*i.e.* two separate initializations) with substantially different GPS constellations (*i.e.* more than two hours apart and on substantially different times of the day). The base receiver should reference a different primary project control monument for the second session. If dual bases are used to reference two primary control monuments 100% of the following survey monuments shall be observed by a minimum of one RTK or PPK observation session from each base reference station:

1. Property Boundary monuments
2. Easement monuments
3. Survey Alignment monuments
4. Etc.

* Minimum verification of 68% of the above listed monuments may be increased to 100% by the
3.8.4 Region Survey Coordinator.

CDOT Class C – TMOSS Horizontal Surveys

3.8.5 All CDOT Class C - TMOSS Horizontal Surveys performed with GPS shall be performed in accordance with the methods and procedures as required in the chapter for either a Static, Fast Static, RTK or PPK survey meeting the Minimum Horizontal Accuracy Tolerance for a CDOT Class C – TMOSS survey for the feature being located (See Chapter 5 – Preliminary Surveys, for additional information).

CDOT Class D – TMOSS Horizontal Surveys

All CDOT Class D – TMOSS Horizontal Surveys performed with GPS shall be performed in accordance with the methods and procedures as required in the chapter for either a Static, Fast Static, RTK or PPK survey meeting the Minimum Horizontal Accuracy Tolerance for a CDOT Class D – TMOSS survey for the feature being located (See Chapter 5 – Preliminary Surveys, for additional information).

Process for State Plane Coordinate Reduction

For CDOT Class A - Primary surveys, once the final adjusted state plane northing and easting coordinates have been calculated the reduction of state plane coordinates to modified project northing and easting coordinates shall be done in the following order:

- 3.8.6
1. State plane coordinates shall be in meters.
 2. One or more base points are selected to calculate the project latitude, longitude, elevation, elevation factor, scale factor, combined factor, and zone. Either one base point may be selected or the average of all points may be used. The zone selected shall be either the North, South or Central zone in accordance with Article 52, CRS, Colorado Coordinate System, and as approved by the Region Survey Coordinator.
 3. Final adjusted state plane coordinates in meters are reduced to modified ground coordinates in meters using the above calculated factors.
 4. Modified ground coordinates in meters (as calculated above) are truncated in both the northing and easting for an even number value such as 200,000 meters in the northing and 400,000 meters in the easting.
 5. Truncated modified ground coordinates in meters are converted to U.S. Survey Feet in accordance with Article 52, CRS, Colorado Coordinate System, using the following conversion factor: One meter equals 3937/1200 feet.
 6. Only after modified ground coordinates in Meters have been truncated shall they be converted to US survey feet. This allows conversion to and from U.S. Survey Feet to Meters, or Meters to U.S. Survey Feet without having to truncate the coordinates and provides a standard procedure for converting state plane coordinates to modified ground coordinates for CDOT use.

3.9 Project Control Diagram (PCD) and Land Survey Control Diagram (LSCD)

Project Control diagram

All CDOT Class A – Primary surveys performed by GPS methods shall have a PCD completed and filed with the Region Survey Coordinator in accordance with Chapter 5 – Preliminary Surveys.

3.9.1

Land Survey Control Diagram

3.9.2 All CDOT Class B – Secondary surveys performed by GPS methods shall have a LSCD completed and filed with the Region Survey Coordinator and deposited in the records with the appropriate county clerk’s office in accordance with Chapter 5 – Preliminary Surveys.

Aerial surveys are excluded from this requirement.

TMOSS Surveys

3.9.3

All CDOT Class C – TMOSS and CDOT Class D – TMOSS surveys performed by GPS methods shall have the final TMOSS survey shown on the Project Control Diagram and/or the Land Survey Control Diagram in accordance with Chapter 5 – Preliminary surveys.

3.10 Horizontal Datums

CDOT Project Datum

3.10.1 Surveying and mapping work, upon which planning, studies and engineering designs are based, shall use the established CDOT project datum. Unless otherwise determined and approved by CDOT Region Survey Coordinator, the horizontal datum shall be the most recent realization of the North American Datum of 1983 (NAD83) as defined by the National Geodetic Survey (NGS). The horizontal control may utilize accepted CDOT and NGS ground based monuments (such as former HARN) and CORS (Continuously Operating Reference Stations).

NAD83(NSRS2007) National Readjustment

3.10.2 On February 10, 2007 NOAA's National Geodetic Survey (NGS) released its NAD83(NSRS2007) readjusted horizontal positions and ellipsoid heights of the National Spatial Reference System (NSRS) to achieve centimeter level consistency with the published NAD83 framework as defined by the latest **Continuously Operating Reference Stations** CORS realization. Using high accuracy GPS data only the readjustment improves the accuracy and consistency of the NSRS and provides a new *Local* and *Network Accuracy* definition for each coordinate.

NGS Readjustment

<http://www.ngs.noaa.gov/NationalReadjustment/>

The above link provides data and information on the National Readjustment.

3.10.3

NAD83(2011) National Adjustment

As part of continuing efforts to improve the NSRS, on June 30, 2012, NGS completed the National Adjustment of 2011 Project. This project was a nationwide adjustment of NGS "passive" control (physical marks that can be occupied with survey equipment, such as brass disk benchmarks) positioned using Global Navigation Satellite System (GNSS) technology. The adjustment was constrained to current NAD83 latitude, longitude, and ellipsoid heights of NGS Continuously Operating Reference Stations (CORS). The CORS network is an "active" control system consisting of permanently mounted GNSS antennas, and it is the geometric foundation of the NSRS. Constraining the adjustment to the CORS optimally aligned the GNSS passive control with the active control, providing a unified reference frame to serve the nation's geometric positioning needs.

NGS National Adjustment of 2011 Project

<https://geodesy.noaa.gov/web/surveys/NA2011/>

The above link provides data and information on the National Adjustment of 2011 Project.

3.11 NGS National Height Modernization Program (NHMP)

General

Height Modernization is a program within NOAA's NGS that provides accurate height information by integrating GPS technology with existing survey techniques. For years, GPS has been used to determine accurate positions (latitude and longitude), but now, by following Height Modernization standards, specifications and techniques, GPS can efficiently establish accurate elevations for all types of positioning and navigational needs.

NGS National Height Modernization Program (NHMP)

<http://www.ngs.noaa.gov/heightmod/index.shtml>

The above link provides information and project specifications to initiate a Height Mod Project or Program.

Guidelines for Establishing GPS-Derived Ellipsoid Heights NOAA Technical Memorandum NOS NGS-58 Version 4.3:

http://www.ngs.noaa.gov/PUBS_LIB/NGS-58.html

The above link provides information and guidelines for establishing GPS derived ellipsoid heights.

Guidelines for Establishing GPS-Derived Orthometric Heights NOAA Technical Memorandum NOS NGS 59 Version 1.5:

https://www.ngs.noaa.gov/PUBS_LIB/NGS592008069FINAL2.pdf

The above link provides information and guidelines for establishing GPS derived orthometric heights.

3.12 Continually Operating Reference Stations (CORS)

General

The NGS coordinates a network of CORS that provide GPS carrier phase and code range measurements that can be applied directly to GPS surveys in support of 3-dimensional positioning.

- 3.12.1. Prior to the NOAA's NGS National Readjustment in 2007, the CORS system enabled positioning accuracies that approached a few centimeters (approximately 6 centimeters horizontally) relative to the NSRS. In March 2002, NGS upgraded NAD83 positions and velocities for all CORS sites so they equal the transformed values of the more recently computed International Terrestrial Reference Frame of 2000 (ITRF00) positions and velocities.

The National Readjustment, released on February 10, 2008, provides horizontal coordinates and ellipsoid heights simultaneously readjusted to achieve centimeter consistency with the published NAD83 framework as defined by the latest CORS realization. Therefore, the NAD83(NSRS2007) published coordinates and CORS coordinate data are realized as one in the same in accordance with NGS specifications and accuracy tolerances. NGS will continually update all CORS positions to be relative to the ITRF00 annually each year.

All CDOT GPS surveys are referenced and tied into HARN through the NSRS as defined by the NGS. Positions obtained by GPS surveys referencing CORS sites may not be relative to the HARN as monumented on the ground, in particular where GPS data did not exist for use in the National Readjustment. The surveyor will need to take a close look at whether using a CORS station in conjunction with HARN or HARND marks will help to strengthen the GPS survey or degrade it.

Additionally, ellipsoid heights obtained from CORS may not agree with the HARN or HARND. A NGS Height Modernization should be initiated to undertake simultaneous leveling and GPS

3.12.2 activities.

CORS Stations use for Static, Fast Static, RTK, or PPK Surveys

CORS stations shall not be used for performing any CDOT Static, Fast Static, RTK, or PPK survey unless approved in advance by the Region Survey Coordinator.

Before any CORS station will be approved for use by the Region Survey Coordinator, the following shall be reviewed and a determination made:

1. The Minimum Horizontal and Vertical Accuracy Tolerance of the GPS survey being performed.
2. The horizontal and vertical accuracy of the CORS station data.

3. How the CORS station is mounted and what it is mounted on.
4. Multipath conditions of the CORS station.
5. The CORS station antenna type.
6. The distance of the CORS station relative to the highway corridor primary control network and the GPS survey being performed.
7. The overall strength of the geometry of the CORS station relative to the highway corridor primary control network and the GPS survey being performed.
8. Sync time the CORS station is broadcasting on relative to the sync time of the GPS receivers performing the survey.

After the above has been reviewed and a determination made to use a CORS station, the stations used shall be verified as to strengthen the GPS network and not degrade it in relation to the HARN and/or HARND by performing a minimally constrained adjustment of the GPS network.

If the CORS station data is determined to degrade the GPS network the CORS station shall not be used as part of the network.

NGS/NOAA CORS

<http://www.ngs.noaa.gov/CORS/>

The above link provides information and downloads of CORS station files.

NGS Cooperative CORS

<http://www.ngs.noaa.gov/CORS/>

The above link provides information about COOP CORS specifications.

3.13 Online Positioning User Service (OPUS)

General

The NGS operates the Online Positioning User Service (OPUS) as a means to provide GPS users easier access to the NSRS.

- 3.13.1 OPUS allows users to submit their GPS data files in [RINEX format](#) to NGS, where the data will be processed to determine a position using NGS computers and software. Each RINEX file that is submitted will be processed with respect to 3 CORS sites. The sites selected may not be the nearest to your site but are selected by distance, number of observations, site stability, etc. The position for your data will be reported back to you via email in both [ITRF and NAD83 coordinates](#) as well as UTM and State Plane Coordinates (SPC) northing and easting.

OPUS use for Static, Fast Static, RTK, or PPK Surveys

- 3.13.2 The National Geodetic Survey On-line Positioning User Service (OPUS) may be used for producing final horizontal and/or vertical (X, Y & Z) positions for CDOT Static, Fast Static, RTK or PPK survey when the minimum number of passive marks with published positions in the current reference frame are not available within or adjacent to the project. OPUS may be used to determine horizontal positions for CDOT Class A – Primary Horizontal Surveys but differential leveling must be used to determine final elevations. Use of OPUS for determining final positions should be coordinated through the Region Survey Coordinator.

It may be used as a tool for verification of the final horizontal and/or vertical positions (X, Y & Z) obtained from these types of surveys.

3.14 Virtual Reference Network (VRN)

General

A VRN is a system composed of receivers and software designed to facilitate real-time GPS/GNSS positioning based on a network of continuously operating reference stations. Several private and public networks exist in Colorado. A VRN allows RTK positioning using a single (properly configured) rover receiver without needing to set up a base receiver. Use of VRN must be approved in advance by the Region Survey Coordinator. Before using a VRN for control or supplemental surveys, the user must first verify that the network is tied to the NSRS and is using the current adjustment of NAD83. If vertical positioning is also needed the user should verify that elevations are based on NAVD88. VRN may be used to establish control as long as it can be proven to meet CDOT accuracy requirements. VRN should not be used for establishing CDOT Class A or CDOT Class B Vertical Surveys but may be used to seed a single point if no benchmarks exist within a reasonable proximity to the project. VRN is not to be used for flowlines, hard surfaces or other features that require high accuracy elevations due to variation in the vertical which changes throughout a day. VRN is most appropriately used when surveying

ROW and property boundary evidence and some staking activities where high accuracy elevations are not required.

REFERENCES:

CDOT has added hyperlinks for all external information and references to the information contained herein.

CDOT, [*CDOT Survey Manual*](#) – 1992, 2003, 2008, 2010, 2011

CDOT, [*CDOT Right-of-Way Manual*](#) – July 2002, November 2020

*Oregon DOT, Updated Survey Standards and Control Guidance for Improved Operations
- MARCH 2021*

CDOT 2019 standard specifications book, <https://www.codot.gov/business/designsupport/cdot-construction-specifications/2019-construction-specifications/2019-specs-book>